NEXT GENERATION TANKER: OPTIMIZING AIR REFUELING CAPABILITIES IN 2030 WITH A DIVESTED KC-10 FLEET

GRADUATE RESEARCH PAPER

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Abstract

This research develops scenarios and models to conduct analysis of alternatives for completion of various world-wide air refueling requirements with the goal of optimizing air refueling capabilities with a divested KC-10 fleet   The intent of introducing the three proposed aircraft was not to advocate a specific airframe, but rather to examine different air refueling capabilities that varied the maximum fuel load available for receiver aircraft and average hourly fuel burn. While assuming a divested KC-10 fleet and a world-wide air refueling requirement of 20-50 million pounds per day, the study, using linear programming models, concluded that the *Proposal C* (large body) aircraft was the best selection amongst the three proposal aircraft introduced in this particular study. After examining each proposal aircraft's ability to deliver fuel to receivers under various sortie durations, the researcher also balanced the expected development and procurement costs. *Proposal C* aircraft was the clear preferred alternative in almost all cases. The only exception was in one scenario where *Proposal B* (KC-46B) aircraft was the best pick. The intent of the study was to stimulate thought while also providing Air Force leaders the requisite information to make the best informed decisions, thus shaping and molding the future construct of the Developmental Planning for the Advanced Air Refueling. Capability Concepts.

Keywords: Next Generation Tanker, KC-Y, KC-X, KC-10 Divestment

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NEXT GENERATION TANKER: OPTIMIZING AIR REFUELING CAPABILITIES IN 2030 WITH A DIVESTED KC-10 FLEET

Chapter 1 – Introduction

"The Air Force will buy 179 KC-46A Pegasus aircraft, the last of which will be delivered in 2028, to replace the Eisenhower-era KC-135 fleet. However, USAF will continue to maintain 200-plus KC-135s, which will be 65-years-old or older when the last Pegasus is delivered. As a result, the KC-Y and KC-Z follow on efforts have to be real programs and they have to get going now."

---Chief of Staff of the Air Force Mark A. Welsh, Feb 14

General Issue

Air refueling is the backbone of our nation's ability to project global reach and combat power. It has enabled the Air Force to transition from a Cold War, in-garrison force to the rapid expeditionary force of today. Without a robust air refueling capability, the U.S. would be limited in their ability to project global power.

The current and projected tanker fleet is composed of large commercial derivative aircraft that can support the extension of airpower from long-range, secure basing, and from current forward area basing. However, emerging challenges of an aging KC-135 fleet and the potential for divesting the KC-10 fleet threaten the ability to project global airpower.

The KC-46A is the first of a planned three-phased (KC-X, KC-Y, KC-Z) approach to eventually replace the United States Air Force's (USAF) aerial refueling fleet. The KC-Y requirement will be closely analyzed in 2020 through an analysis of alternatives (AoA). The KC-Z AOA will occur the following decade.

The KC-46A is the USAF's newest air-to-air refueling (AAR) aircraft and will be equipped with significant technological improvements designed to enhance operations and increase mission effectiveness. In comparison to most of the current tanker fleet, some of the improved capabilities include receiver AAR receptacle, boom and drogue operations on the same sortie, and pre-installed fittings for aeromedical evacuation stations on all aircraft. For the first time in tanker aircraft history, delivery will include: defense capabilities; chemical, biological, radiological, and nuclear survivability; theater tactical data link; secure voice; global command and control data link; text chat and email with controlling Air and Space Operations Center. The KC-46A will also have the ability to host communications gateway payloads to extend line-of-sight (LOS) communication networks. Along with its robust AAR capabilities, the KC-46A will provide a significant boost to Air Mobility Command's (AMC's) global airlift missions.

The KC-46A will provide air refueling support for both conventional global strike and nuclear deterrence operations; support air superiority through air refueling of fighter, bomber, attack, special operations, and transport aircraft; and support employment of combat units deploying to areas of operations. Finally, the KC-46A will also support the C2 core function as a communications gateway when equipped with a roll-on gateway system to provide connectivity between tactical network partners in theater.

The final KC-46A force structure is estimated to be 179 total aircraft inventory aircraft by fiscal year 2028 (Grismer, 2011). KC-46A units will be based on the Total Force Integration (TFI) concept and will operate with a combined crew ratio of 3.5 (2.0 Active Duty host/1.5 Reserve Component tenant; 2.5 Reserve Component host/1.0 Active Duty tenant). At overseas locations, the KC-46A will operate at a 3.0 crew ratio (HQ AMC/A8PF, 2015).

The USAF is in the early stages of the procurement process for the next generation tanker (also known as KC-Y). The current focus is on specific capabilities in order to ensure a robust air refueling enterprise and continued global mobility. The intent of this graduate research paper is to examine various world-wide air refueling requirements in order to optimize air refueling capabilities with a divested KC-10 fleet. The research designed and modeled a variety of linear programs with three proposed aircraft. The intent of introducing the three proposed aircraft was not to advocate a specific airframe. The proposed aircraft were used to examine different air refueling capabilities that varied the maximum fuel load available to receiver aircraft and average hourly fuel burn. All of the linear programs assumed a divested KC-10 fleet and a world-wide air refueling requirement of 20-50 million pounds per day.

The intent of the study was to stimulate thought and debate while also providing Air Force leaders information that can help them make the best informed decisions in order to shape and mold the future construct of the developmental planning for the advanced air refueling capability concepts in order to purchase the best possible size and optimized number of next generation tanker aircraft. The Mobility Air Force (MAF) air refueling enterprise continues to evolve and the researcher hopes that this graduate research project can make a small step in its advancement.

Problem Statement

A next generation/follow-on to the KC-46A (179 aircraft by 2028) will be necessary to ensure a robust air refueling fleet and continued U.S. global mobility. In the past, the Air Force procured high-technology, successful platforms. Unfortunately, costs have accelerated faster than capabilities and the number of platforms has decreased. Innovation will ensure a powerful and flexible air mobility force that is affordable in both acquisition and operating cost.

Research Question

What is the right-sized next generation tanker (KC-Y) that best balances various combatant commander air refueling requirements in 2030 and a shrinking national defense budget?

Research Focus

This research focused on various world-wide air refueling requirements in order to optimize air refueling capabilities with a divested KC-10 fleet. A variety of techniques were used in order to acquire data for this research. The most important technique was interviewing the Air Mobility Command (AMC) experts who possess an incredible amount of experience and data. The researcher's main AMC contacts were Mr. Pete Szabo and Mr. Robert Nagel who provided valuable data and guidance throughout the research process. Another technique used to focus this research was an analysis of various combatant commander air refueling requirements. After combatant commander analysis, the researcher developed three proposed aircraft. The proposed aircraft were used to examine different air refueling capabilities that varied the maximum fuel load available for receiver aircraft and average hourly fuel burn. Next the researcher developed four main categories that were considered in order to design the linear programs for this research. The four categories that needed to be developed were: predicted air refueling fleet in 2030, aircraft performance characteristics, tanker sortie length requirements and worldwide air refueling requirements. After these four categories were defined, linear programs were run in order to answer how many proposal aircraft were required to meet the various air refueling requirements. Finally, the expected development and procurement costs were calculated in order to better understand which of the three proposed aircraft were able to meet mission requirements for the best value.

Methodology

The methodology used in this research consisted of future combat requirement scenario generation along with quantitative analysis using linear programming. A total of 36 linear programs were designed and used in this research. All of the linear programs assumed a divested

KC-10 fleet and a world-wide air refueling requirement of 20-50 million pounds per day. The average tanker sortie duration varied between 5-11 hours.

Assumptions/Limitations

The following are assumptions/limitations of this research:

1. A divested KC-10 fleet
2. Daily receiver requirement of 20-50M pounds of fuel per day
3. Two-hour minimum landing fuel
4. All test aircraft are 100% reliable
5. Each aircraft is only available once a day
6. Weather and runway allow maximum gross weight takeoff
7. A daily aircraft availability of 225 KC-135 and 144 KC-46
8. Aircraft performance measures as listed in Table 1:

Table 1: Aircraft Performance Assumptions

Aircraft	T/O Fuel	Fuel Burn	Min Landing Fuel	Max Fuel Available	Development Procurement Cost
KC-135	200,000	11,291	22,582	177,418	N/A
KC-46	210,287	12,000	24,000	186,287	N/A
Proposal A (Multi-Role)	136,300	8,700	17,400	118,900	$235M
Proposal B (KC-46B)	210,287	12,000	24,000	186,287	$250M
Proposal C (Large Body)	302,270	14,305	28,610	273,660	$500M

Implications

The intent of the study is to stimulate thought and debate while also providing Air Force leaders valuable information that can help them make the best informed decisions in order to shape and mold developmental planning for the advanced air refueling capability concepts in order to purchase the best possible size and optimized number of next generation tanker aircraft.

The Mobility Air Force Refueling enterprise continues to evolve and the researcher hopes that this graduate research project can make a small step in its advancement.

Chapter 2 -- Literature Review

Chapter Overview

A thorough and exhaustive literature study has been performed during this research project. Sources include trade journals, defense technical papers, various books and periodicals, other research papers, and world-wide web resources. This literature review first examines the general KC-135 history and rise of air refueling. The review then transitions into the KC-X acquisition process that ultimately resulted in the purchase of 179 KC-46As, followed by a review of the Budget Control Act of 2011 (Sullivan, 2013). The literature review briefly examines the Mobility Capabilities and Requirements Study for 2016 (Jackson, 2009). Finally, the literature review concludes with predicting the environment in the 2030 (Shaud, 2011).

KC-135 History

The KC-135 Stratotanker was originally developed in 1954 by Boeing engineers from a Boeing 707 platform (White, 2002). They developed the technology for the Air Force during the 1950s to facilitate Strategic Air Command's strategy of nuclear deterrence using their long-range bombers with refueling to attack the Soviet Union. Today, most tanker derivatives in the world are 707 derivatives and Boeing is still the only manufacturer of the flying boom used by most Air Force aircraft for refueling. Boeing officially discontinued manufacturing the KC-135 on December 7, 1964 after building over 700. A re-engine program to replace the KC-135s obsolete turbojet engines with more powerful, more efficient high-bypass turbofans was instituted, ultimately creating the KC-135R model (White, 2002).

Boeing has been approached about possible future upgrades to the 707 to extend its operating life for 20 to 40 more years. Boeing's Military Aerospace Support spokesman, Paul Guse, responded by saying the 707 line has long been discontinued and may not be the best platform for the Air Force to place its trust in for that long of a time. Boeing touts their 767 as a replacement for the KC-135, saying that the 767 is in plentiful supply and is well supported into the next decade by a “support infrastructure worldwide” and would be a much wiser choice for the Air Force (White, 2002).

KC-X Acquisition

The Air Force projected that the KC-135 E and R models have lifetime flying hour limits of 36,000 and 39,000 hours, respectively. According to the Air Force, only a few KC-135s would reach these limits before 2040, but at that time some of the aircraft would be about 80 years old (HQ AMC/A9A, 2015). The Air Force estimates that their current fleet of KC-135s has between 12,000 to 14,000 flying hours per aircraft, which is approximately 33 percent of the lifetime flying hour limit. Nevertheless, these aircraft are currently over 40 years old and plagued with maintenance problems resulting in an increase in costs.

Between 1993 and 2003, the amount of KC-135 depot maintenance work doubled, and the overhaul cost per aircraft tripled. “In 1996 it cost $8,400 per flight hour for the KC-135, and in 2002 this had grown to $11,000” (Munfakh, 2009). The Air Force’s 15-year cost estimates project further significant growth through fiscal year 2017. For example, operations and support costs for the KC-135 fleet are estimated to grow from about $2.2 billion in fiscal year 2003 to $5.1 billion (2003 dollars) in fiscal year 2017, an increase of $2.9 billion, or over 130 percent, which represents an annual growth rate of about 6.2 percent (Kennedy, 2006).

The USAF has decided to replace the KC-135 fleet. However, since there are over 500 KC-135s, these aircraft will be replaced gradually, with the first batch of about 100 aircraft to be replaced first. The effort to replace the KC-135 has been marked by intense controversy. The initial plan was to lease Boeing KC-767 tankers on a sole-source basis; Boeing is the only

American company with the requisite industrial capability to manufacture large-body aircraft. As such, the KC-767 was initially selected in 2002 (Gertler, 2011) and in 2003 Boeing was awarded a $20 billion contract to lease KC-767 tankers to replace the KC-135 (Munfakh, 2009).

KC-X was the first of three planned programs intended to recapitalize the Air Force's air refueling fleet. Eventually, the KC-X program is expected to acquire 179 new, commercial off-the-shelf airliners modified to accomplish air refueling. Both Boeing and a consortium consisting of Northrop Grumman and European Aeronautic Defense and Space Company (EADS) competed for KC-X. Boeing offered a variant of the 767-200, while Northrop Grumman submitted a version of the Airbus 330-200.

On February 29, 2008, the Air Force awarded the KC-X contract to Northrop Grumman. The initial $12.1 billion KC-X contract covers purchase of the first 68 KC-45s of the anticipated 179 aircraft. Boeing protested the Air Force's decision to the Government Accountability Office (GAO). GAO upheld the Boeing protest, and in July, Defense Secretary Robert Gates announced that he would reopen the tanker competition (O'Rourke, 2009).

On 21 August 2013, Boeing and the Air Force completed a critical design review (CDR) for the KC-46. The CDR was held from 8–10 July, and was completed one month ahead of the original schedule, which planned on the review to be finished on 24 September. With the CDR complete, the KC-46 design is now set and production and testing can proceed. Assembling of the wing for the first aircraft began on 26 June 2013. Flight testing of the Boeing 767-2C airframe, which will be reconfigured into the KC-46, was scheduled to begin in mid-2014. The first fully equipped KC-46 tanker is projected to fly in 2015. Boeing is contracted to build four test aircraft and deliver 18 combat-ready tankers by August 2017. The Air Force is to buy 179 KC-46s, with all delivered by 2028 (Flight Global, 2013; Boeing, 2013).

On 12 December 2013, Boeing joined the wings and fuselage for the first 767-2C to be adapted into a KC-46A (Tirpak, 2014). On 23 December 2013, the first two PW4062 engines were delivered (Sullivan, 2014). The first of four 767-2C provision freighters will complete assembly by the end of January 2014. Once assembled, it will go through ground vibration and instrumentation testing and have body fuel tanks added. The first test flight occurred in December 2014 and included measuring its rate of climb and descent. The Engineering Manufacturing and Design (EMD) model will be integrated with instrumentation, electronics, and technologies needed to become a military-standard KC-46A in 2015. Seven low-rate production KC-46s are to be delivered in 2015, 12 in 2016, and 15 delivered annually from 2017 to 2027. The KC-46A can carry 212,000 pounds of fuel, 10 percent more than the KC-135, and 65,000 pounds (29,000 kg) of cargo. It has both a probe and drogue and a boom and receptacle to conduct multiple refueling missions on a single mission. Survivability is improved with infrared countermeasures and the aircraft has limited electronic warfare capabilities. The airframe can be configured to carry 114 passengers and to serve as an aero-medical evacuation aircraft. The last of four test aircraft began assembly on 16 January 2014 (Sullivan, 2014).

Budget Control Act of 2011

The Department of Defense's Fiscal Year (FY) 2015 budget submission provides the resources necessary to protect and advance U.S. interests and to execute the updated defense strategy, although at increased levels of risk for some missions relative to the planned funding levels in the FY 2014 budget. This budget complies with the limits established for FY 2015 in the Bipartisan Budget Act of 2013, but over the remainder of the Future Years Defense Program (FYDP), it exceeds the estimated limits on base budget discretionary Department of Defense funding under current law by $115 billion. These estimated limits reflect the automatic reductions of the caps on Government-wide discretionary funding established in the Budget Control Act of 2011 (BCA).

The *Estimated Impacts of Sequestration-Level Funding* Report (Funding, 2014) outlines the impacts the department would face today in having to plan and operate at the sequestration levels and documents the significant cuts to forces, modernization, and readiness that would be required at those levels. Of course, BCA-level funding would have similar impacts for non-defense programs, and any increase in defense discretionary caps should be matched by an equivalent increase in the non-defense caps. For defense, the *Estimated Impacts of Sequestration-Level Funding* Report illustrates the additional warfighting risk the department will incur if the BCA's automatic reductions persist. The department will continue to review and refine this plan as conditions warrant, so while this report shows a specific set of impacts, those impacts may change.

The automatic reductions required by the BCA would impose significant cuts to department resources that would significantly increase risks both in the short- and long-term. These cuts would be in addition to several reductions in planned funding that the Department has already absorbed. Over the past several years, planned DoD spending has been significantly reduced for the following reasons:

1. To comply with the original discretionary spending caps in the BCA, FY 2012 enacted appropriations and the FY 2013 President's Budget reduced DoD funding by $487 billion compared with the ten-year plan in the FY 2012 President's Budget.
2. The March 2013 sequestration reduced base budget FY 2013 DoD funding by an additional $32 billion.

3. Consistent with the revised caps in the BCA, FY 2014 enacted appropriations reduced Department of Defense funding by $31 billion compared with the President's Budget request, and the FY2015 President's Budget requested $45 billion less than was planned in the FY 2014 budget.

Together, these cuts total almost $600 billion. Accordingly, the department's planned budgets across the FYDP have been substantially reduced. The services have already reduced force structure and planned modernizations prior to any additional cuts discussed here. Additionally, compensation savings have been assumed at both funding levels. If these proposed compensation reforms are not enacted, the Department will have no choice but to make further cuts elsewhere in the budget that will deprive our troops of the training and equipment they need to succeed in battle.

With the addition of projected sequestration-level cuts for FY 2016 through 2021, reductions to planned defense spending for the ten-year period from FY 2012 to 2021 will exceed $1 trillion. If sequestration-level cuts persist, our forces will assume substantial additional risks in certain missions and will continue to face significant readiness and modernization challenges. These impacts would leave our military unbalanced and eventually too small to meet the needs of our strategy fully.

At sequestration-level funding, major reductions from the FY 2015-2019 President's Budget request would include:

1. Reducing one squadron of F-35 aircraft (cutting acquisition of 15 aircraft)
2. Eliminating the fleet of KC-10 tankers
3. Cutting operational surface combatant ships by 7 in FY 2019
4. Cutting procurement of 8 ships across the FYDP

5. Divesting the Global Hawk Block 40 fleet
6. Divesting the Predator fleet beginning in FY 2016
7. Eliminating planned purchases of Reaper aircraft in FY 2018 and FY 2019
8. Reducing Service readiness funding by $16 billion over the FYDP to include approximately $9 billion in depot/ship maintenance, which would further increase Service maintenance backlogs

Mobility Capabilities and Requirements Study 2016

The Mobility Capabilities and Requirements Study 2016 (MCRS-16) (Jackson, 2009) developed three cases to evaluate a broad spectrum of military operations which are linked to notional strategic environments that could be used to inform the QDR and support possible decisions regarding future mobility force structure.

Case 1: U.S. forces conduct two nearly simultaneous large-scale land campaigns, and respond to three nearly simultaneous Homeland Defense (HLD) consequence management events with corresponding aerospace control levels (ACLs) and maritime awareness presence levels, which take place concurrent with the land campaigns.

Case 2: U.S. forces conduct a major air/naval campaign concurrent with the response to a large asymmetric campaign and respond to a significant HLD consequence management event with corresponding ACLs and maritime awareness presence levels. This case includes scenarios and operations that are part of the QDR Security Environment.

Case 3: U.S. forces conduct a large land campaign against the backdrop of an ongoing long-term irregular warfare campaign. The case includes three nearly simultaneous HLD consequence management events with corresponding ACLs and maritime awareness presence levels. (See Figure 1).

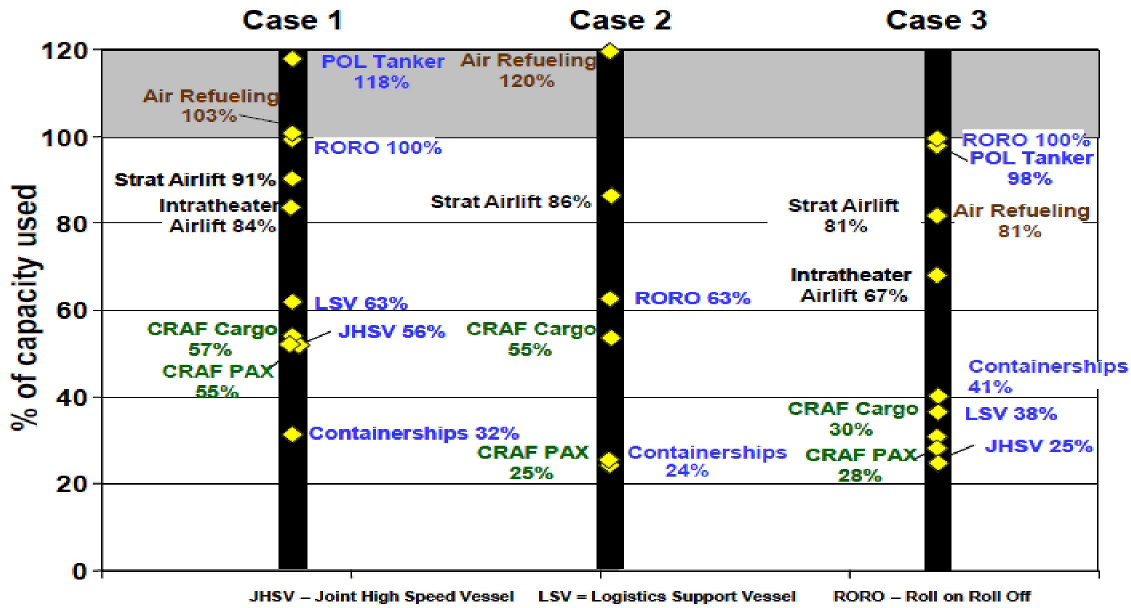

Figure 1. Mobility System Utilization by MCRS Case (Jackson, 2009)

The current tanker inventory consists of 474 USAF aircraft (415 KC-135s/59 KC-10s) and 79 USMC KC-130s. This inventory does not satisfy the peak demands of two of the three cases assessed. The demand ranged from a low of 383 KC-10s/KC-135R-equivalents and 66 KC-130s to a high of 567 KC-10s/KC-135R-equivalents and 79 KC-130s. However, a modernized fleet would require fewer aircraft to meet the same demand due to lower depot times and greater capability (Jackson, 2009).

Predicting the Environment in 2030

Whether the scenario is in Asia, the Middle East, or even the Levant currently in Syria and Iraq, Air-Sea Battle has been envisioned from its inception as a set of operational concepts to preserve combat effectiveness in areas where technology based anti-access/aerial denial (A2/AD) strategies, coupled with disadvantageous geographic or diplomatic access, challenge United States ability to project power rapidly and persist with high operational tempo (Coldfelter, 2014).

Many have construed the Department of Defense Joint Operational Access Concept, which emphasizes attacks-in-depth across broad areas, indirect approached, and deception to reduce the pressure on forward basing (Coldfelter, 2014). While this concept updates the American way of high-end warfare, it does not fully addresses the true A2/AD challenge: how to maintain sensor and weapons density at distance, over time, without forward bases or aircraft carriers. Overcoming this challenge requires more than achieving cross-domain synergy, a term describing better joint force integration and incorporation of emerging capabilities such as cyber warfare. It also requires unconventional thinking about how the United States military Services combine sensors, weapons, and platforms to create new disruptive capabilities (Coldfelter, 2014).

Summary

The KC-135 has proven itself as an extraordinary viable national asset since 1954. Current engineer estimates believe that the KC-135 fleet will be able to continue to fly into 2030. However, it is now time to begin replacing the KC-135 fleet. The KC-X was the first of three planned programs intended to recapitalize the Air Force's air refueling fleet. It is now time to look at KC-Y. We need thoroughly examine the KC-X acquisition process and try to avoid the same pitfalls during the KC-Y process. The Budget Control Act of 2011 is a subject that needs to be considered in the KC-Y/Z procurement process. Currently, the KC-10 fleet is still part of the Air Force inventory. This researcher believes that the KC-10 fleet will be divested before 2030. The assumption that KC-10s will be part of the Air Force inventory in 2030 is something that could potentially cause severe shortfalls in the air refueling enterprise.

The Mobility Capabilities and Requirements Study 2016 (MCRS-16) assumes an operation KC-10 fleet in the three cases that were used to evaluate a broad spectrum of military operations linked to notional strategic environments. Of the three cases studied, only Case 3 had enough air refueling assets to reach mission objectives. Case 1 and 2 required 103% and 120%, respectively. The MCRS-16 assumed an operational fleet of Air Force KC-10s. This researcher can't help but wonder what the MCRS-16 results would be with a divested fleet of KC-10s due to the Budget Control Act of 2011.

Predicting the environment in 2030 is something that needs to be strongly considered while deciding KC-Y capabilities. There is no way to fully forecast the anti-access/area denial (A2/AD) environments in 2030 or whether KC-10 will be divested. However, the Air Force planners need to get as close as possible. This researcher hopes that this graduate research paper will be make a small step in its advancement.

Chapter 3 -- Methodology

Chapter Overview

The methodology used in this research was linear programming. A total of 36 linear programs were designed and used in this research. There were four main categories that needed to be considered in order to design the linear programs for this research (see Figure 2). The four categories were: predicted air refueling fleet in 2030, aircraft performance characteristics, tanker sortie length requirements and worldwide air refueling requirements. After these four categories were defined, linear programs were run in order to answer how many proposal aircraft were required to meet the various air refueling requirements. Finally, the expected development and procurement costs were calculated in order to better understand which of the three proposed aircraft were able to meet mission requirements for the best value.

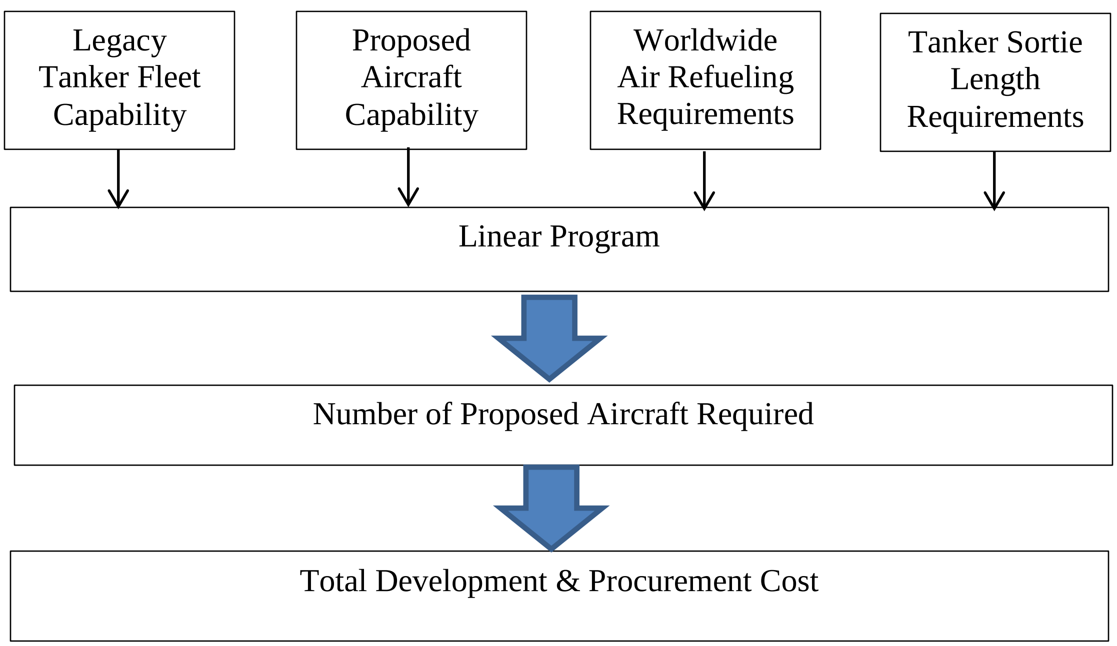

Figure 2. Methodology Block Diagram

Predicted Air Refueling Fleet in 2030

Working closely with Mr. Pete Szabo, the predicted air refueling fleet that the analysis professionals at Air Mobility Command (AMC) are currently using is summarized in Table 2. To help maintain the continuity in methodology, the same predicted air refueling fleet in 2030 that AMC is currently using was used in this research as well.

Table 2: Predicted AMC Tanker Aircraft in 2030 with a Divested KC-10 Fleet

	Primary Mission Aircraft Inventory	Mission Capable Rate	Daily Aircraft Available
KC-135	265	85%	225
KC-46	160	90%	144

According to Air Force Pamphlet 10-1403, Primary Mission Aircraft Inventory (PMAI) is: Aircraft authorized to a unit for performance of its operational mission. Primary authorization forms the basis for the allocation of operating resources to include manpower, support equipment, and flying hours funds (Pamphlet, 2011).

The mission capable (MC) rate is used to determine expected daily aircraft available. Basically, the MC rate includes factors such as depot maintenance and other various things that do not allow all aircraft to fly on a daily basis. Using the KC-135 as an example, the PMAI is 265 with a MC rate of 85% (Table 2) which equates to a daily aircraft available rate of 225.25 KC-135s (265 PMAI *.85 MC =225.25 Daily Aircraft). For the purposes of this research, the daily aircraft available was rounded down to an even 225 KC-135 aircraft available. The daily aircraft available for the KC-46 didn’t require any rounding because the answer was exactly 144 aircraft.

Aircraft Performance Characteristics

A summary of the aircraft performance characteristics used in this research is found in Table 3.

Table 3: Methodology Aircraft Performance Characteristics

Aircraft	Takeoff Fuel	Fuel Burn	Minimum Landing Fuel	Maximum Fuel Available
KC-135	200,000	11,291	22,582	177,418
KC-46	210,287	12,000	24,000	186,287
Proposal A (Multi-Role)	136,300	8,700	17,400	118,900
Proposal B (KC-46B)	210,287	12,000	24,000	186,287
Proposal C (Large Body)	302,270	14,305	28,610	273,660

The takeoff fuel and fuel burn was derived from a number of means. For the KC-135, the takeoff fuel and fuel burn (per hour) was derived from Air Force Pamphlet 10-1403 (USAF, Year). The KC-46 takeoff fuel and fuel burn (per hour) was supplied by Mr. Pete Szabo. At the time this paper was written, the KC-46 had only had one successful sortie (source). *Proposal A* aircraft takeoff fuel and fuel burn (per hour) were derived by using the Airbus 400M performance factors. This research is not focusing on a specific airframe; it is focusing on specific capability (delivering a certain amount of fuel over a specified tanker sortie duration). However, the researcher thought it would be best to use an aircraft that is a known quantity and currently exists with a proven performance track record. *Proposal B* aircraft use the same takeoff fuel and fuel burn rate as the KC-46. For the same reasons as *Proposal A* aircraft, the researcher thought it would be best to use an aircraft that currently exists and use that specific performance versus randomly creating performance data. *Proposal C* aircraft data was based off a Boeing 777 (B-777). Since there is not a B-777 air refueling tanker in existence (to this researcher's knowledge), the takeoff fuel was based off the Boeing *Airplane Characteristics* Publication that defines a B-777 high gross weight takeoff fuel as 302,270 pounds. Of course with military modifications, the takeoff fuel amount could possibly be increased, but for the purposes of this research, no additional assumptions were made in regards to takeoff fuel. *Proposal C* aircraft's fuel burn rate was derived from Air Force Pamphlet 10-1403, fuel burn rate for the B-777 (Pamphlet, 2011).

The minimum landing fuel was calculated taking each aircraft's individual hourly fuel burn and multiplying it by two. This research is covering a macro set of scenarios with will require some mission to have the tanker carry more or less fuel depending on specific situations. For the purposes of this research, it was decided that the overall contingency fuel for each aircraft would be two hours.

The maximum fuel available was calculated by taking each aircraft's takeoff fuel and subtracting it from the minimum landing fuel. For example, the KC-135s takeoff fuel is 200,000 pounds and minimum landing fuel is 22,582 pounds which equals a maximum fuel available of 177,418 pounds (200,000 – 22,582 = 177,418).

Tanker Sortie Length Requirements

In order to determine tanker sortie length requirements, three scenarios were developed for this research (Table 4). After extensive research and prior tanker experience, the researcher decided to break the average tanker sortie lengths into three time groups (5/8/11 hours) and use three scenarios.

Table 4: Tanker Sortie Length Requirements

Tanker Sortie Length Requirements			
	5.0 Hour Sortie	**8.0 Hour Sortie**	**11.0 Hour Sortie**
Scenario 1	60%	35%	5%
Scenario 2	20%	60%	20%
Scenario 3	5%	35%	60%

Scenario 1 is defined as short tanker missions that offload a large percentage (60% of all sorties) of fuel in a relatively short time frame (5 hours). These missions would include a majority of large receiver aircraft that could take large amounts. Such aircraft would include aircraft such as C-5s, C-17s, and B-52s.

Scenario 2 is defined as medium tanker sortie missions that would offload a large percentage (60% of all sorties) an average time frame (8 hours). These missions would most likely include a mix of different receiver aircraft.

Scenario 3 is defined as long tanker sortie missions that would most likely take a long time to travel to the air refueling track or a scenario where smaller aircraft (fighter aircraft) would require the tanker to stay airborne for a long period of time. In this case 60% of the tanker missions would be airborne for 11 hours.

Worldwide Air Refueling Requirements

For the purposes of this research, daily air refueling requirements were determined to be 20, 30, 40 and 50 million pounds per day. Table 5 shows a breakdown of the fuel requirements for each scenario.

To provide an example of how this chart was calculated, let’s examine 20M pounds of fuel per day Scenario 1. As we discussed in the tanker sortie length, Scenario 1 assumes 60% of the sorties are 5 hours, 35% are 8 hours and 5% are 11 hours. These percentages were then used under each sortie duration and multiplied by the total amount of fuel required. For example, the 20M pounds of fuel per day Scenario 1 is 12,000,000 (20,000,000 lbs * .60 = 12,000,000 lbs).

Table 5: Worldwide Air Refueling Requirements

Worldwide Air Refueling Requirements			
	5.0 Hour Sortie	**8.0 Hour Sortie**	**11.0 Hour Sortie**
20M lbs Fuel Scenario 1	12,000,000	7,000,000	1,000,000
20M lbs Fuel Scenario 2	4,000,000	12,000,000	4,000,000
20M lbs Fuel Scenario 3	1,000,000	7,000,000	12,000,000
30M lbs Fuel Scenario 1	18,000,000	10,500,000	1,500,000
30M lbs Fuel Scenario 2	6,000,000	18,000,000	6,000,000
30M lbs Fuel Scenario 3	1,500,000	10,500,000	18,000,000
40M lbs Fuel Scenario 1	24,000,000	14,000,000	2,000,000
40M lbs Fuel Scenario 2	8,000,000	24,000,000	8,000,000
40M lbs Fuel Scenario 3	2,000,000	14,000,000	24,000,000
50M lbs Fuel Scenario 1	30,000,000	17,500,000	2,500,000
50M lbs Fuel Scenario 2	10,000,000	30,000,000	10,000,000
50M lbs Fuel Scenario 3	2,500,000	17,500,000	30,000,000

Summary

In order for the researcher to design and run the 36 linear programs, the following constraints were determined:

1. The predicted air refueling fleet in 2030 would consist of a daily aircraft availability of 225 KC-135 and 144 KC-46s (Table 2).
2. Aircraft performance characteristics used a variety of resources in order to try to provide the most realistic performance data available (Table 3).
3. Tanker Sortie Length requirements varied the average sortie lengths of 5/8/11 hours (Table 4).

4. Worldwide Air Refueling Requirements were determined to be 20/30/40/50 Million pound receiver requirement per day (Table 5).

Chapter 4 -- Results and Analysis

Chapter Overview

It requires a very unusual mind to undertake the analysis of the obvious.

---Alfred North Whitehead

This chapter analyzes the linear program results, development and procurement costs of the three proposal aircraft, and concludes with a calculated break-even cost for each proposal aircraft.

Linear Program Results

The results of the linear programs discussed in Chapter 3 can be found below in Table 6. Due to the number of assumed KC-135 and KC-46 aircraft in 2030, five of the linear programs didn't require any proposal aircraft. These five categories were all three scenarios for 20 million pounds of fuel per day and the first two scenarios that required 30 million pounds of fuel per day. A sensitivity analysis was conducted in order to better understand the results. The sensitivity analysis revealed that the binding constraint in all cases was the 144 KC-46s. The researcher then decreased the mission capable (MC) rate of both the KC-46s and KC-135s to 80% and 75%, respectively. The 10% reduction of the assumed MC rates didn't change the optimization results. The KC-46s continued to remain the binding constraint in all cases. A key takeaway from these results is that in these specific cases, increasing the available number of KC-46s will continue to reduce the number of KC-135s needed. Inversely, an increase of KC-135's will have no effect on any of the scenarios.

For the remaining seven scenarios, proposal aircraft were required. As suspected, the larger the aircraft the fewer that were required for each given scenario. These results are instructive for decision makers to consider how many aircraft would be needed for specific scenarios. The major limiting factor with Table 7 is that these answers do not answer how much it would cost in terms of development and procurement costs. The following section will address the development and procurement costs now that the research knows how many aircraft are required for each scenario.

Table 6: Number of Proposal Aircraft Required Per Scenario

Number of Proposal Aircraft Required Per Scenario			
	Proposal A	Proposal B	Proposal C
20M Scenario 1	0	0	0
20M Scenario 2	0	0	0
20M Scenario 3	0	0	0
30M Scenario 1	0	0	0
30M Scenario 2	0	0	0
30M Scenario 3	174	96	45
40M Scenario 1	36	22	10
40M Scenario 2	200	114	54
40M Scenario 3	493	251	118
50M Scenario 1	194	117	63
50M Scenario 2	493	233	116
50M Scenario 3	830	402	190

Estimated Development and Procurement Cost Results

Now that the researcher calculated the specific number of proposal aircraft that were needed for the various scenarios with linear programming. It is now possible to explore each proposal aircraft's total cost (in terms of development and procurement costs) for each scenario.

Table 7 shows the estimated development and procurement costs of the three proposal aircraft. *Proposal A* aircraft's cost was based off the 2013 development and procurement cost of the Airbus A-400M that was paid by France (Pintat, 2014). *Proposal B* aircraft's cost was based off the 2013 development and procurement of the United States 179 tankers (KC-X acquisition), which was provided be the Government Accountability Office in 2013 (Sullivan, 2013). *Proposal C* aircraft's cost was based off the 2005 Rand Study (Kennedy, 2006).

Table 7: Estimated Development and Procurement Cost

Estimated Development & Procurement Cost (**$M**)	
	Estimated Cost Per Aircraft
Proposal A	$235
Proposal B	$250
Proposal C	$500

Table 8 shows the total projected scenario cost for each proposal aircraft to meet the various air refueling scenarios. Not surprising, the five linear programs that resulted in zero need for proposal aircraft had a total cost of $0. For the other 12 scenarios that required proposal aircraft, *Proposal C* aircraft was the cheapest alternative in 11/12 scenarios (91.7%). The only exception was the Scenario 1 (60% of all tanker sorties are 5 hours) for 50 million pounds of fuel per day. In this case, *Proposal B* aircraft was the most cost effective choice.

Table 8: Total Projected Scenario Cost

Total Projected Scenario Cost ($M)			
	Proposal A	Proposal B	Proposal C
20M Scenario 1	$0	$0	$0
20M Scenario 2	$0	$0	$0
20M Scenario 3	$0	$0	$0
30M Scenario 1	$0	$0	$0
30M Scenario 2	$0	$0	$0
30M Scenario 3	$40,890	$24,000	$22,500
40M Scenario 1	$8,460	$5,500	$5,000
40M Scenario 2	$47,000	$28,500	$27,000
40M Scenario 3	$115,855	$62,750	$59,000
50M Scenario 1	$45,590	$29,250	$31,500
50M Scenario 2	$115,855	$58,250	$58,000
50M Scenario 3	$195,050	$100,500	$95,000

Breakeven Costs (Sensitivity Analysis)

Table 9 shows the assumed development and procurement costs and breakeven costs for each proposal aircraft using sensitivity analysis. For example, *Proposal A* aircraft was unable to meet any of the scenario requirements for the least costs. However, if the development and procurement costs of *Proposal A* aircraft could be ≤$114.3M, *Proposal A* aircraft would meet (or exceed) all scenario requirements for the lowest price. Essentially, if the development and procurement costs can be reduced to the breakeven costs found in Table 9, that specific aircraft would be able to meet all scenario requirements for the lowest price. The notion used when the sensitivity analysis for breakeven costs were calculated was that the assumed development and procurement costs for the other two aircraft do not change.

Table 9: Breakeven Costs (Sensitivity Analysis)

Breakeven Costs (**$M**)		
	Assumed Cost	Breakeven Cost
Proposal A	$235M	**≤$114.3M**
Proposal B	$250M	**≤$227.3M**
Proposal C	$500M	**≤$464M**

Chapter 5 -- Conclusions and Recommendations

Conclusions of Research

This research concluded that the best overall right-sized tanker that would be able to best meet combatant commander requirements while balancing the development and procurement costs was *Proposal C* (large body) aircraft. *Proposal C* aircraft was able to meet (or exceed) all of the scenarios at the lowest costs in all scenarios except for one occasion. The scenario that *Proposal C* aircraft did not meet was the 50M pounds of fuel per day Scenario 1. In this single case, *Proposal B* (KC-46B) aircraft was the best alternative. However, if *Proposal C* aircraft's development and procurement costs could be reduced from the assumed $500M per aircraft to $464M, *Proposal C* aircraft would be the best alternative for every category that required a proposal aircraft.

Significance of Research

The significance of this research examines what is the right-sized aircraft that best balances the various needs of Combatant Commanders while balancing the costs associated with purchasing our Next Generation Tanker (KC-Y). Air refueling capability will be improved with a recapitalized tanker fleet through the acquisition of the KC-46 and the modernization of the remaining tanker fleet through service life extension programs to achieve baseline configurations. With this approach, the air refueling fleet in 25 years will contain the first KC-46 increment and the second tanker recapitalization increment, commonly referred to as the KC-Y. The MAF construct will mitigate the risk of its aging fleet by retaining some modernized KC-135s in the inventory until they are replaced through recapitalization. Future tankers must be capable of supporting both conventional air refueling operations and an expanded capability to refuel the next generation of remotely piloted vehicles and conduct refueling in contested airspace to defeat the anticipated growth in anti-access/area denial (A2/AD) environments.

Recommendations for Future Research

This research only examined the development and procurement costs of the three proposal aircraft. A recommendation for future research would be to look at each proposal aircraft's total life cycle costs. As you can see from Figure 3, acquisition costs are just the tip of the iceberg when it comes to the cradle-to-grave costs associated with purchasing a major weapons system. A well informed and modeled Monte Carlo technique would most likely lead to the best approach in trying to determine total life cycle costs.

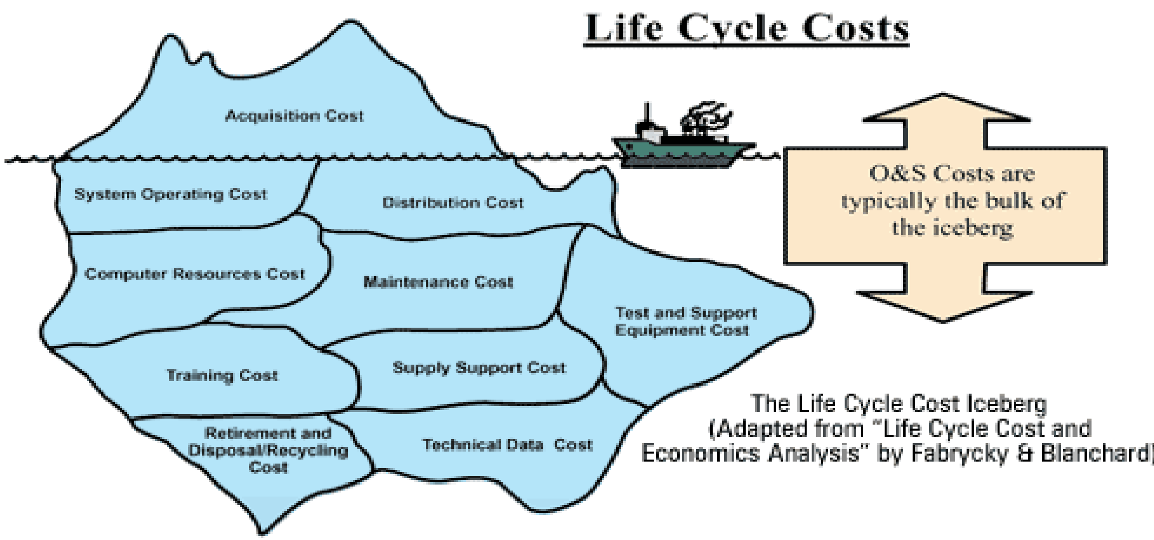

Figure 3. Lifecycle Costs

Another recommendation for future research would be to examine other potential capabilities for a Next Generation Tanker. Some specific capabilities could potentially be: low observable technologies, unmanned tankers, a fully self-deployable aircraft, and the capability to land on semi-prepared runways.

Finally, another recommendation for future research is to thoroughly examine the potential A2/AD environment in 2030 and develop tactics, techniques and procedures for the future tanker fleets to be successful in such environments.

Summary

"Defense Budgets will likely continue to flatten…even with declining purchasing power, we still have to do more with the same or fewer resources, squeezing every last bit of capability from our current and future weapons systems."

---Chief of Staff of the Air Force Norton A. Schwartz, Oct 10

The intent of this research was to instill thought-provoking debate about what the right-sized next generation tanker (KC-Y) should be. As General Schwartz stated in October 2010, we need to squeeze every last bit of capability for our current and future weapon systems. It is my belief that *Proposal C* aircraft is the best balance of meeting operational needs with a shrinking Defense Budget.

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Appendix A: Advanced Air Refueling Capability Concepts Standard Terminology

Term	Definition	Reference
KC-Y	Focus is on **programmatic** continuance of the second of three increments of tanker recapitalization, specifically beyond 179 KC-46A aircraft (circa 2027-2028)	AMC/CC guidance, 24 Sep 14
KC-Z	Focus is on **programmatic** continuance of the third of three increments of tanker recapitalization, specifically beyond the KC-Y aircraft	AMC/CC guidance, 24 Sep 14
Next Generation Tanker	A follow-on tanker concept to the KC-46A. Focus is on **capabilities** to ensure a robust air refueling enterprise and continued U.S. global mobility. It is not platform- or program-specific. Capability Concepts are being examined in the DP effort, Advanced Air Refueling Capability Concepts (AARCC).	AARCC Team defined
Next Generation Air Dominance (NGAD)	The Combat Air Forces (CAF) analysis of platforms that support or provide Air Superiority in the 2030+ timeframe. NGAD is also a DP effort.	Air Combat Command defined
Advanced Air Refueling Capability Concepts (AARCC)	AARCC is a Developmental Planning (DP) effort focusing on capabilities for a Next Generation Tanker that would accomplish Air Force tanker operations in 2030 and beyond. The scope is not platform specific, but will distinguish how we currently perform aerial refueling and what is required for aerial refueling in 2030+ timeframe. The DP effort is examining advanced concepts and promising technologies that could be incorporated into a next generation tanker.	AARCC Team defined
Developmental Planning (DP)	DP is homework. It is early systems engineering, technical analysis, and pre-program planning activities; driven by capability needs, gaps, and opportunities; focus is on conceptual material solutions; at the current stage of the AARCC effort, it is not requirements definition.	AFMC Development Planning Guide, Jun 2010

Anti-Access (A2)	Those capabilities, usually long-range, designed to prevent an advancing enemy from entering an operational area	Joint Operational Access Concept (JOAC)
Area Denial (AD)	Those capabilities, usually of shorter range, designed not to keep the enemy out but to limit his freedom of action within the operational area	Joint Operational Access Concept (JOAC)
Permissive Environment	The operational environment where an adversary's systems, due to limits in range, precision, or their own access, can only conduct harassment and disruption attacks. U.S. and allied operations can be effectively conducted despite adversary interference; i.e., low risk. Also, the operational environment in which host country military and law enforcement agencies have control as well as the intent and capability to assist operations that a unit intends to conduct.	AARCC Team defined. Also see: JP 3-30, 11 Aug 11 JP 3-35, 31 Jan 13
Contested Environment	The operational environment where long-range adversary systems and a near-peer's most capable air and surface combatants can conduct attacks. U.S. and allied assets can operate effectively here, but only with mutual support; i.e., high risk	FY14 Air-Sea Battle (ASB) Implementation Master Plan (IMP)
Highly Contested Environment	The operational environment where virtually all of a near-peer adversary's systems can conduct attacks. Only the most capable U.S. and allied assets can operate effectively here, with mutual support; i.e., extreme risk	FY14 Air-Sea Battle (ASB) Implementation Master Plan (IMP)
Dispersal Basing	Term intended to encapsulate several basing concepts, such as Distributed Operations and Cluster Basing. Designed to complicate adversary targeting by dispersing aircraft to outlying airfields.	AARCC Team defined
Capability	The ability to execute a specified course of action (a capability may or may not be accompanied by an intention)	JP 1-02, Department of Defense Dictionary of Military and Associated Terms (15 Aug 14)

Capability Requirement	A capability which is required to meet an organization's roles, functions, and missions in current or future meet an organization's roles, functions, and missions in current or future operations. To the greatest extent possible, capability requirements are described in relation to tasks, standards, and conditions in accordance with described in relation to tasks, standards, and conditions in accordance with the Universal Joint Task List or equivalent DOD Component Task List. If a capability requirement is not satisfied by a capability solution, then there is also an associated capability gap which carries a certain amount of risk until eliminated. A requirement is considered to be 'draft' or 'proposed' until validated by the appropriate authority. Also called a "need" or "requirement."	JP 1-02, Department of Defense Dictionary of Military and Associated Terms (15 Aug 14)
Theater Air Refueling	This concept is typically a warfighter balance of two metrics: 1) "Booms in the Air" - theater requirement roughly equivalent to the term "air refueling points," normally with one aircraft representing one refueling point; and, 2) "Fuel in the Air" - total theater offload requirement for air refueling assets, normally expressed in millions of pounds of fuel per day.	AARCC Team defined. Also see: AFDD 2-62, 19 Jul 99 JP 3-17, 30 Sep 13
Dedicated Tanker	A tanker aircraft designed to provide a robust, general purpose capability for the primary mission of air refueling with high efficiency, and a secondary, limited capacity for other capabilities, such as airlift or Aeromedical Evacuation (AE). Example: KC-135	AARCC Team defined
Multi-Role Tanker	"A tanker aircraft designed to perform both a general purpose air refueling mission with moderate efficiency as well as a general purpose bulk cargo airlift and AE mission. Typically associated with a wide-body airliner design. Example: KC-10A, KC-46A."	AARCC Team defined

Enhanced Persistence	This attribute represents the ability of assets to remain airborne for extended periods of time by means of air refueling. Possible enabling concepts and technologies include autonomy and enhanced aircrew life support systems (e.g.: reduced vibration, reduced cabin altitude, increased cabin humidity).	AARCC Team defined
Enhanced Range	Aircraft designs that take advantage of advanced technologies for the purpose of increasing aircraft range. This capability could allow basing of forces and operations outside the reach of adversary long range Anti-Access capabilities. This contrasts with using the efficiency gains provided by advanced technologies to increase mission payload and maintain the same operating range. This capability concept would allow overflight of en route locations and increase cargo velocity, reduce the amount of fuel to move forward in the Battlespace (enabled by fuel efficiency), and a significantly increased range/offload curve. i.e., Global Reach	AARCC Team defined
Short Takeoff and Landing (STOL)	The ability of an aircraft to clear a 50-foot (15 meters) obstacle within 1,500 feet (450 meters) of commencing takeoff or in landing, to stop within 1,500 feet (450 meters) after passing over a 50-foot (15 meters) obstacle	JP 1-02, Department of Defense Dictionary of Military and Associated Terms (17 Oct 07)
Reduced Takeoff & Landing (RTOL)	The term RTOL is in contrast to the term STOL. This term refers to an unspecific takeoff and landing capability that would be less than current tanker aircraft (including KC-46A). The AARCC Team considered that a tanker with true 1500' takeoff/landing STOL capability likely would be of limited operational utility because of the aircraft's extreme fuel capacity penalty.	AARCC Team defined
Increased Survivability	Broad category of capabilities to allow Next-Generation Tanker operations in a 2030+ threat environment. The term is deliberately broad/open-ended so as not to constrain discussion, or to imply specific survivability strategies with pre-loaded expectations.	AARCC Team defined
Tanker	The combined metric of range and offload	AARCC Team

Range/Offload Curve	that defines air refueling (AR) capability.	defined
Autonomy	Broad attribute encompassing capabilities of aircraft to operate while exploiting any number of potential technological off-ramps along the spectrum ("degrees of autonomy") of autonomous operations, including enhanced aircrew SA, reduced manning, optional manning, or any number of fractional models of automation, possibly without significant configuration changes or loss of mission capability and flexibility. Key features are enhancement of mission capability and flexibility. The sum total of these capabilities could provide the potential for enormous manpower savings as well as new capabilities, such as enhanced persistence and automated air refueling.	AARCC Team defined
Remotely Piloted (Unmanned) Aircraft Operations	Currently referred to as Remotely Piloted Aircraft (RPA) -- unmanned aerial systems (UAS) consisting of primary flight controls being located on the ground, with ground-based crew controlling the aircraft.	AARCC Team defined
Initial Capabilities Document (ICD)	The ICD is the most common starting point for new capability requirements. An ICD supports the acquisition process at several points, including the MDD, the AoA, or other analysis, as required. The ICD also documents the intent to partially or wholly address identified capability gaps with a non-materiel solution, materiel solution, or some combination of the two.	JCIDS Manual, 19 Jan 12

Appendix B: AFPAM 10-1403 Air Mobility Planning Factors

Fuel Burn Rates

Aircraft Type	Fuel Burn Rate	Aircraft Type	Fuel Burn Rate	Aircraft Type	Fuel Burn Rate
C-130	4,533	B-747	26,800	F-15E	13,244
C-130J	4,500	B-767	10,552	F-16	5,795
C-17	21,097	B-777	14,305	A/OA-10	3,996
C-5	24,033	DC-8	13,916	F/A-18C/D	7,417
C-5M	22,110	DC-10	20,616	F/A-18E/F	8,623
KC-10	18,948	MD-11	17,511	EA-6B	7,102
KC-135R	11,291	F-22A	11,118	E-6A/B	10,747
A-330	10,260	F-15C	11,189	AV-8B	5,461

NOTE: Fuel burn rates extracted from AFPAM 23-221, Fuels Logistics Planning, 22 December 2006 (converted to lbs/hr using 6.7 lbs/gal conversion rate). Fuel burn rates are for planning purposes only. Actual rate varies according to mission profile, AC model, configuration, altitude, airspeed etc.

Tanker Offload Capabilities

Aircraft	Takeoff Gross	Takeoff Fuel Load	Max Offload Available (lbs) [3]			
			Mission Radius			
			500nm	1000nm	1500nm	2500nm
KC-135R/T	322,500	200,000	122,200	99,400	76,400	30,700
KC-10	590,000	340,000	233,500	195,200	156,000	78,700

NOTES:

1. This table was extracted from AFTTP 3.1.KC-10/KC-135 2 November 2008
2. Based on Sea level, standard day, 10,000-ft dry runway.
3. Offload data based on 1-hour orbit.
4. Cargo carried will reduce fuel load on a 1:1 basis.
5. All KC-10 and a limited number of KC-135 aircraft are air refuelable, providing increased range, off-load, and loiter capabilities.

Appendix C: Linear Program Examples

Proposal A Aircraft Scenario 3 (50Million Pounds)

Aircraft	T/O Fuel	Fuel Burn	Min Landing Fuel	Max Fuel Available
KC-135	200,000	11,291	22,582	177,418
KC-46	210,287	12,000	24,000	186,287
Proposal A (Multi-Role)	136,300	8,700	17,400	118,900

Offload Available (per tanker)			
Aircraft	5.0 Hr Sortie	8.0 Hr Sortie	11.0 Hr Sortie
KC-135	120,963	87,090	53,217
KC-46	126,287	90,287	54,287
Proposal A (Multi-Role)	75,400	49,300	23,200

Scenario 3 (Long Sorties)			
[redacted]	5.0 Hr Sortie	8.0 Hr Sortie	11.0 Hr Sortie
	5%	35%	60%
50M lbs Fuel	2,500,000	17,500,000	30,000,000

Let:	A = KC-135
[redacted]	B = KC-46
	X = Proposal A

Minimize: A + B + 10X

	5 Hour			8 hr			11 hr						
	KC-135	KC-46	Proposal A	KC-135	KC-46	Proposal A	KC-135	KC-46	Proposal A				
	1.0	0.0	32.0	0.0	0.0	355.0	224.0	144.0	443.0		Total Aircraft		
	1	1	10	1	1	10	1	1	10	=	8,669.0		
Proposed Aircraft Required			1			1			1	=	830.0	<=	1,000
KC-135s Available	1			1			1			=	225.0	<=	225
KC-46s Available		1			1			1		=	144.0	<=	144
5Hr Sortie Fuel Available	120,963	126,287	75,400							=	2,533,763.0	>=	2,500,000
8 Hr Sortie Fuel Available				87,090	90,287	49,300				=	17,501,500.0	>=	17,500,000
11 Hr Sortie Fuel Available							53,217	54,287	23,200	=	30,015,536.0	>=	30,000,000

Total Available Fuel	50,050,799

Proposal B Aircraft Scenario 3 (50Million Pounds)

Aircraft	T/O Fuel	Fuel Burn	Min Landing Fuel	Max Fuel Available
KC-135	200,000	11,291	22,582	177,418
KC-46	210,287	12,000	24,000	186,287
Proposal B (KC-46B)	210,287	12,000	24,000	186,287

Offload Available (per tanker)			
Aircraft	5.0 Hr Sortie	8.0 Hr Sortie	11.0 Hr Sortie
KC-135	120,963	87,090	53,217
KC-46	126,287	90,287	54,287
Proposal B (KC-46B)	126,287	90,287	54,287

Scenario 3 (Long Sorties)			
[redacted]	5.0 Hr Sortie	8.0 Hr Sortie	11.0 Hr Sortie
	5%	35%	60%
50M lbs Fuel	2,500,000	17,500,000	30,000,000

Let:	A = KC-135
[redacted]	B = KC-46
	Y = Proposal B

Minimize: A + B + 10Y

	5 Hour			8 hr			11 hr						
	KC-135	KC-46	Proposal B	KC-135	KC-46	Proposal B	KC-135	KC-46	Proposal B				
	2.0	1.0	17.0	1.0	0.0	193.0	222.0	143.0	192.0		Total Aircraft		
	1	1	10	1	1	10	1	1	10	=	4,389.0		
Proposed Aircraft Required			1			1			1	=	402.0	<=	1,000
KC-135s Available	1			1			1			=	225.0	<=	225
KC-46s Available		1			1			1		=	144.0	<=	144
5 Hr Sortie Fuel Available	120,963	126,287	126,287							=	2,515,092.0	>=	2,500,000
8 Hr Sortie Fuel Available				87,090	90,287	90,287				=	17,512,481.0	>=	17,500,000
11 Hr Sortie Fuel Available							53,217	54,287	54,287	=	30,000,319.0	>=	30,000,000

Total Available Fuel	50,027,892

Proposal C Aircraft Scenario 3 (50Million Pounds)

Aircraft	T/O Fuel	Fuel Burn	Min Landing Fuel	Max Fuel Available
KC-135	200,000	11,291	22,582	177,418
KC-46	210,287	12,000	24,000	186,287
Proposal C (Large Body)	302,270	14,305	28,610	273,660

Offload Available (per tanker)

Aircraft	5.0 Hr Sortie	8.0 Hr Sortie	11.0 Hr Sortie
KC-135	120,963	87,090	53,217
KC-46	126,287	90,287	54,287
Proposal C (Large Body)	202,135	159,220	116,305

Scenario 3 (Long Sorties)

[redacted]	5.0 Hr Sortie	8.0 Hr Sortie	11.0 Hr Sortie
	5%	35%	60%
50M lbs Fuel	2,500,000	17,500,000	30,000,000

Let:	A = KC-135
[redacted]	B = KC-46
	Z = Proposal C

Minimize: A + B + 10Z

	5 Hour			8 hr			11 hr						
	KC-135	KC-46	Proposal C	KC-135	KC-46	Proposal C	KC-135	KC-46	Proposal C		Total Aircraft		
	20.0	0.0	1.0	52.0	142.0	1.0	151.0	2.0	188.0				
	1	1	10	1	1	10	1	1	10	=	2,267.0		
Proposed Aircraft Required			1			1			1	=	190.0	<=	1,000
KC-135s Available	1			1			1			=	223.0	<=	225
KC-46s Available		1			1			1		=	144.0	<=	144
5 Hr Sortie Fuel Available	120,963	126,287	202,135							=	2,621,395.0	>=	2,500,000
8 Hr Sortie Fuel Available				87,090	90,287	159,220				=	17,508,654.0	>=	17,500,000
11 Hr Sortie Fuel Available							53,217	54,287	116,305	=	30,009,681.0	>=	30,000,000
										Total Available Fuel	50,139,730		

Appendix D: Quad Chart

Next Generation Tanker: Optimizing Air Refueling Capabilities in 2030 with a Divested KC-10 Fleet

Maj Christopher MacDonald
Advisor: Darryl Ahner, Ph.D.
Advanced Studies of Air Mobility (ENS)
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Problem Statement

A next generation/follow-on to the KC-46A (179 aircraft by 2028) will be necessary to ensure a robust air refueling fleet and continued U.S. global mobility. In the past, the Air Force procured high-technology, successful platforms. Unfortunately, costs have accelerated faster than capabilities and the number of platforms has decreased. Innovation will ensure a powerful and flexible air mobility force that is affordable in both acquisition and operating cost.

Research Question

What is the right-sized Next Generation Tanker (KC-Y) that best balances various Combatant Commander air refueling requirements in 2030 and a shrinking national defense budget?

AIR FORCE INSTITUTE of TECHNOLOGY

Results & Analysis

Number of Proposal Aircraft Required Per Scenario

	Proposal A (A-400M)	Proposal B (KC-46B)	Proposal C (B-777)
30M Scenario 1	0	0	0
30M Scenario 2	0	0	0
30M Scenario 3	174	96	45
40M Scenario 1	36	22	10
40M Scenario 2	200	114	54
40M Scenario 3	493	251	118
50M Scenario 1	194	117	63
50M Scenario 2	493	233	116
50M Scenario 3	830	402	190

Total Projected Scenario Cost ($M)

	Proposal A (A-400M)	Proposal B (KC-46B)	Proposal C (B-777)
30M Scenario 1	$0	$0	$0
30M Scenario 2	$0	$0	$0
30M Scenario 3	$40,890	$24,000	$22,500
40M Scenario 1	$8,460	$5,500	$5,000
40M Scenario 2	$47,000	$28,500	$27,000
40M Scenario 3	$115,855	$62,750	$59,000
50M Scenario 1	$45,590	$29,250	$31,500
50M Scenario 2	$115,855	$58,250	$58,000
50M Scenario 3	$195,050	$100,500	$95,000

Methodology

After various constraints were identified and three proposal aircraft were introduced; multiple linear programs were ran in order determine the optimal number of proposal aircraft for various scenarios. Finally, estimated development and procurement costs were calculated in order to understand which of the proposal aircraft was able to meet the scenario requirements for the best value.

Recommendations

The best overall right-sized tanker that would be able to best meet combatant commander requirements while balancing the development and procurement costs is Proposal Aircraft C (i.e. B-777). Proposal Aircraft C was able to meet (or exceed) all of the scenarios at the lowest costs in all scenarios except for one occasion.

Collaboration

AMC/A8XC, AMC/A9A

Curriculum Vitae

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BS, Business Management; University of Maryland, 2001

PROFESSIONAL HISTORY

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2013– 2014: Aide-de-Camp, NATO Training Mission-Afghanistan, Kabul, Afghanistan
2011 – 2013: Assistant Director of Flying Operations/C-130 Instructor Pilot, 302d Airlift Wing, Peterson AFB, Colorado
2010 – 2011: Group Executive Officer/KC-135 Instructor Pilot, 22d Maintenance Group, McConnell AFB, Kansas
2008 – 2010: Readiness Flight Commander/KC-135 Aircraft Commander, 349th Air Refueling Squadron, McConnell AFB, Kansas
2005 – 2008: Student Pilot, Whiting Field, Florida; Vance AFB, OK; Altus AFB, OK
2003 – 2005: Aircraft Maintenance Unit Assistant Officer in Charge, 46th Aircraft Maintenance Squadron, 46th Test Wing, Eglin AFB, Florida

MAJOR AWARDS AND DECORATIONS:

Bronze Star
Meritorious Service Medal with one oak leaf cluster
Air Medal with seven oak leaf clusters
Aerial Achievement Medal with one oak leaf cluster
Air Force Commendation Medal with one oak leaf cluster
Air Force Achievement Medal
Air Force Combat Action Medal
NATO Medal
46th Test Wing Company Grade Officer of the Year (2003)
22 Air Refueling Wing Company Grade Officer of the Year (2009)
Airlift/Tanker Association Gen “Dutch” Huyser Pilot Award (2010)

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14. ABSTRACT
This research develops scenarios and models to conduct analysis of alternatives for completion of various world-wide air refueling requirements with the goal of optimizing air refueling capabilities with a divested KC-10 fleet The intent of introducing the three proposed aircraft was not to advocate a specific airframe, but rather to examine different air refueling capabilities that varied the maximum fuel load available for receiver aircraft and average hourly fuel burn. While assuming a divested KC-10 fleet and a world-wide air refueling requirement of 20-50 million pounds per day, the study, using linear programming models, concluded that the *Proposal C* (large body) aircraft was the best selection amongst the three proposal aircraft introduced in this particular study. After examining each proposal aircraft's ability to deliver fuel to receivers under various sortie durations, the researcher also balanced the expected development and procurement costs. *Proposal C* aircraft was the clear preferred alternative in almost all cases. The only exception was in one scenario where *Proposal B* (KC-46B) aircraft was the best pick. The intent of the study was to stimulate thought while also providing Air Force leaders the requisite information to make the best informed decisions, thus shaping and molding the future construct of the Developmental Planning for the Advanced Air Refueling.

15. SUBJECT TERMS
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